TECHNICAL REPORT 98-3

PAVEMENT FRICTION OF ASPHALT SURFACE COURSES CONTAINING BLENDS OF WAPPINGER DOLOMITE AND NON-CARBONATE AGGREGATES

INTERIM REPORT

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FRICTION

Executive Summary

Adequate friction on asphalt pavements is a basic highway safety concern. Moreover, it has been demonstrated to be of concern only when roads are wet. During these wet periods, the amount of friction available to a vehicle is dependent upon its speed, its tires, and the texture of the pavement. The New York State Department of Transportation has control over only one of these factors - the pavement texture, through its choice of aggregate for the large size fraction in asphalt mixes.

It is generally accepted in the U.S. that a measured pavement friction number (FN_{40}) of about 32 provides friction adequate for the safe operation of motor vehicles. New York adopted $FN_{40} = 32$ as the "Programmatic Design Target Minimum Friction Number", intended, by the specification, to provide at least that amount of friction throughout a pavement's life (see Note).

For decades, New York and most others, thought that asphalt pavement friction was dependent upon the cumulative polishing affect of traffic, and that friction would gradually diminish as a pavement aged. In the early 1990s, the Department learned that traffic intensity, usually expressed as daily traffic volume, rather than cumulative traffic, could be used to predict a "minimum anticipated terminal polish". This terminal polish is a minimum friction level that will be maintained throughout the life of the pavement, under similar traffic conditions. Actual measured friction varies seasonally, reaching its maximum during winter and its minimum during summer.

The Department relies primarily on a programmatic approach to ensure adequate friction, but, uses a segmental approach, for specific highway segments.

On the programmatic side, specifications for friction aggregates were originally based on a friction inventory of the state system. Since 1980, these specifications have been continuously monitored by testing a matrix of pavement sections selected to represent the various aggregates and mix types currently in service under a variety of traffic intensities. Pavement sections selected for the matrix were all open-flow, flat, straight highway segments chosen because they are the safest to test and free of variables that could affect results. From this database, the Department believed it could determine Minimum Anticipated Friction Numbers (MAFN) for given aggregate types at given traffic volumes, under all conditions.

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The Department recently concluded that such an approach does not account for the actual frictional performance of aggregates under certain conditions. The added polishing effect of vehicle acceleration and deceleration, associated with geometrics such as intersections, was suspected of being a significant factor affecting friction. A small-scale scanning study, completed in 1998, was conducted to confirm or refute the need for further study of the suspected influence. The results did indeed confirm the need for further investigation.

Department staff learned, through the scanning study, that the model for predicting minimum friction (MAFN) could not be relied upon to predict the level of friction at high traffic volume intersections. The staff also learned that the friction-reducing influence of very high traffic volumes, in the vicinity of intersections, could extend much farther beyond the stop bars than hypothesized, easily in excess of a tenth of a mile.

The segmental approach to ensuring adequate friction is founded on the Department's Statewide Accident Surveillance System (SASS), more specifically on the Wet weather Priority Investigation Locations (Wet PILs) identified by the system. Wet PILs are highway segments where the proportion of wet weather accidents to total accidents is significantly higher than the average for the state.

In 1997, the Department performed friction testing on 110 Wet PIL segments identified by SASS. Of these, fully 89 were located in Region 8, 10, and 11. The 1998 list of 132 Wet PILs includes 109 in this downstate area. This concentation of Wet PILs, coupled with our early indications on intersectional performance, led to the conclusion that the megalopolis of the lower Hudson Valley, New York City, and Long Island is a system of congested roadways, where high traffic volumes selectively reduce friction where it is most needed.

Within this megalopolitan context, aggregate blends of Wappinger Dolomite and non-carbonate rocks cannot be relied on to provide "adequate" friction at high traffic intersections, curves, ramps, and lane merges throughout much of the lower Hudson Valley, New York City, and Long Island. In this area, Wappinger Dolomite/ non-carbonate blends should be restricted from use.

NOTE: The Programmatic Design Target Minimum Friction Number ($FN_{40} = 32$) has been used by the Department since the early 1970s. A friction number (FN_{40}) is an expression of a pavement's coefficient of friction, as measured by the drag-force trailer (ASTM E 274) at 40mph, multiplied by 100. Friction is, by convention, either measured at 40mph or measured at another speed and mathematically adjusted to 40mph, using an experimentally derived gradient, and allows for comparison ampng pavements.

The greatest frictional demands placed upon pavement are in areas of geometics (intersections, curves, lane merges, grades). Vehicles entering these areas are travelling at speeds that vary, depending on traffic conditions. The Programmatic Design Target Minimum Friction Number ($FN_{40} = 32$) was selected to meet the normal demands of traffic at all speeds.

PAVEMENT FRICTION OF ASPHALT SURFACE COURSES CONTAINING BLENDS OF WAPPINGER DOLOMITE AND NON-CARBONATE AGGREGATES

Introduction

It is the mission of the New York State Department of Transportation to ensure our customers, those who live, work, and travel in New York State, have a "safe, efficient, balanced, and environmentally sound transportation system". In applying the mission statement to pavement management, the Department maintains specifications for aggregates that allow the use of local materials to the greatest possible extent. The Department continuously refines aggregate specifications by monitoring pavement performance, particularly with respect to friction. Intensive pavement friction testing, supported by an accident monitoring system, allow the Department to provide adequate friction while optimizing aggregate usage.

The lithology of the coarse aggregate particles (plus 3.2mm) govern the level of friction in hot mix asphalt concrete pavements. In addition, traffic characteristics play an important role in modifying friction levels. The Department measures pavement friction at representative sites using the most accurate and highly regarded system available (ASTM E 274). It uses data from these sites to revise friction aggregate specifications, as necessary, to programmatically assure that a minimum coefficient of friction is met or surpassed, for the service life of the pavement. This programmatic design target minimum (PDTM) coefficient of friction is expressed as a friction number of 32, measured according to ASTM E 274 at 40 mph ($FN_{40} = 32$).

Aggregates produced from the Wappinger Dolomite Formation are shipped from quarries in Dutchess, Orange, and Rockland counties to markets in the lower Hudson Valley, New York City, and Long Island. Because of its abundant supply and uniformly high quality, the Wappinger Dolomite has attained wide usage in highway construction projects. Its use as a friction aggregate in hot mix asphalt surface courses was restricted in 1992 to a blend containing a minimum of 20% non-carbonate aggregate particles. An analysis of recent friction data, on now mature, properly- blended pavements constructed since 1993, reveal that, under certain critical traffic conditions, these Wappinger Dolomite/ non-carbonate blends may not provide the desired level of friction.

Background

The Department's standard specifications permitted all durable coarse aggregates in hot mix asphalt pavement surface courses until the mid-1960s. A study of pavement friction by the Department's Bureau of Physical Research, begun in 1960, found a strong relationship between aggregate type and pavement friction. This work led to the Department's adoption of friction aggregate specifications in 1969. The specification permitted a hot mix asphalt surface course to contain the following coarse aggregates: non-carbonates (ie. Granite, traprock, sandstone), dolomite, limestone having 10% or more acid insoluble residue (AIR: sand-sized silica), and limestone mixed with 20% or more non-carbonate particles. The friction performance of each of these aggregate classifications was independantly verified to be capable of having adequate friction after accumulating 10 million vehicle passes (cumulative traffic).

Technical Report 92-1, Performance of Dolomites as High Friction Aggregates (Interim Report), published by the Department's Materials Bureau in January 1992, demonstrated that traffic volume (intensity), as well as aggregate type, are the principal controlling factors of friction in asphalt pavements. The report concluded that pavement sites containing dolomites, having acid insoluble residues (AIR) of less than 15%, provided adequate friction for low traffic volumes. Since Wappinger Dolomite (AIR typically 5% to 15%) was used predominantly in the lower Hudson Valley, New York City, and Long Island, where roadway traffic is typically high volume, the Department revised the aggregate specifications to restrict its use. The revised standard specifications required Wappinger Dolomite to be mixed with 20% or more of non-carbonate aggregates for all pavements in Region 8, Region 10, and Region 11 that exceed 4,000 lane AADT. The Department, in 1992, did not yet have high traffic volume pavement friction data sites containing other low AIR dolomites. However, in 1996, having gathered new data, the Department further revised the standard specifications for friction aggregates to require all low AIR dolomites (AIR less than 17%) to be mixed with a minimum of 20% non-carbonate aggregates. This revision applied statewide, to all pavements with high traffic volumes (AADT >8000 for 2-lane roads, AADT >13,000 for roads with 4 lanes or more), and built on the 1992 restrictions. In addition, the 1996 specification revision applied this requirement to all pavements, regardless of traffic volume, in Region 8 (except those in Columbia and Ulster counties), Region 10, and Region 11.

The Department measured the pavement friction on Rt. 9, Poughkeepsie, Dutchess Co., in 1996, in response to a 1995 PIL designation that represented 100% Wappinger Dolomite in the top mix. However, Rt 9 had been resurfaced in 1995 with Wappinger Dolomite coarse aggregate blended with about 35% granite, a non-carbonate aggregate. This section of Rt.9 carries a high volume of traffic and has many signalized intersections. The friction test results unexpectedly included several data points that fell below the desired level. More extensive retesting of this Rt. 9 area showed the lowest friction was within intersection areas and the higher friction was in "open-road" areas. Since all representative pavement sites, used by the Department to monitor friction, represented "open-road" conditions, the Materials Bureau conducted a scanning study of

pavement friction at high traffic intersections to evaluate friction under those special stop-and-go, congested conditions. An "open-road" condition is one in which the highway is straight and flat, and the traffic is free flowing. The study concluded that the historical "open-road" pavement friction inventory data cannot be used to predict friction within high traffic volume intersection areas. This finding led the Department to investigate pavement friction data in the lower Hudson Valley, New York City, and Long Island where roadways are typically high traffic and operating routinely under congested conditions. The results of this study, as they relate to the Wappinger Dolomite/ non-carbonate blends, is reported below.

Discussion

Pavement Friction Results

The results of testing pavement sections containing Wappinger Dolomite/ non-carbonate blends is summarized in **tables 1,2, and 3**. These sections include Pavement Friction Inventory sites, Test by Request (TBR) sites, and Priority Investigation Locations (PILs). Discussion of data is beneath each table. **Figure A** is a friction profile of the intersection of Rt. 25A and Glen Cove Rd. in Roslyn, Nassau Co., LI. It was derived from overlapping continuous measurements throughout the intersection area. Friction measurements (FN_{40}) generally fall within the range of 26 to 32. At the time of testing, the pavement was about 2 years old. This intersection was part of the intersection scanning study completed in March 1998. **Figure B** is a friction profile along Rt 347 in Suffolk Co. that begins in the vicinity of the State Office Building in Hauppauge and extends eastward for about 11 miles. The Lane AADT ranges between 12K and 15K, throughout, with intersections as indicated. The section was tested every 0.3 mi as a scanning profile to compare friction performance among three aggregate types: traprock, granite, and Wappinger Dolomite/ granite blends. Two sections containing the blend were included. The blend section at the west end of the profile was paved in 1996 and was tested with 1+ years of traffic; the blend section at the east end of the profile was paved in 1994 and was tested with 3+ years of traffic. Friction on both 100% non-carbonate (traprock and granite) sections is above the PDTM of 32. Friction on the sections containing Wappinger Dolomite/ granite blends is both above and below the PDTM but, on the more mature section at the eastern end of the profile, friction is generally below the PDTM of 32. **Figure C** is a map of Rt 135 and Rt 24 including their cloverleaf interchange, paved in 1994 with a Wappinger Dolomite/ granite blend. The average measured friction number (FN_{40}) on the Rt 135 mainline, a controlled access, 6-lane highway (Lane AADT = 14K), is 39. The southbound ramp from Rt 135 to westbound Rt 24 was also friction tested. The average friction number for that portion of the ramp marked "A" is 31, while the average for the portion marked "B" is 29. This information demonstrates the relationship between friction on mainline sections and that on ramp sections. A similar relationship has been identified on curved sections as well (Table 2, TBRs 171 a and b).

Table 1

OPEN-ROAD FRICTION PERFORMANCE OF BLENDS OF WAPPINGER DOLOMITE AND NON-CARBONATE COARSE AGGREGATE

Site No.	Lane AADT	Average Friction
TBR-96-171-b	2.5K	53.6
TBR-96-168-b	3.3K	50.4
TBR-96-171-a	6.3K	49.4
TBR-96-168-a	6.6K	47.1
1009(10%OSS)	7.8K	49.5
1002(17%OSS)	10.3K	37.6
TBR-96-167	13.5K	48.0
1017	14.7K	36.3
LANE CAPACITY APPROXIMATELY 15K*		
1018	29.0K **	28.0
1016	29.4K **	29.5
1019	32.5K **	29.0
1020	32.5K **	32.9

* Traffic at or above this has a service level of D, E, or F.
** Six lane controlled access at service level E

This table shows results of friction tests on pavement sections without intersections, ramps, curves, merges, or grades. Traffic flow, for those sections with Lane AADTs greater than 15K, is often congested, with reduced speeds and stoppages. The measured friction at these very high traffic volume sections, averaged over three years of measurement, is close to or below the Programmatic Design Target Minimum (FN_{40} =32).

Table 2

FRICTION PERFORMANCE OF WAPPINGER DOLOMITE / NON-CARBONATE BLENDS IN OPEN-ROAD AND IN AREAS OF GEOMETRICS

Site No.	Lane AADT	Average Friction Number			
		Geometrics		Open-Road	Red.
TBR 167	13.5K	**43.2**	(Merges)	**48.0**	**4.8**
TBR 168a	6.6K	**42.5**	(Intersections)	**47.1**	**4.6**
TBR 171a	6.3K	**45.3**	(Curves & Intersect.)	**49.4**	**4.1**
TBR 171b	2.5K	**47.9**	(Curves & Intersect.)	**53.6**	**5.7**
Rt. 9 (S. Of Poughkeepsie)	9.6K	**32.8**	(Intersections)	**38.3**	**5.5**

In each of the above pavement sections, friction measured within areas containing geometrics (intersections, curves, and merges) were averaged. All open-road friction measurements were also averaged for each pavement section. **A reduction in friction number (FN) is common to each location.**

Table 3

PAVEMENT SITES CONTAINING WAPPINGER DOLOMITE/ NON-CARBONATE BLENDS IN AREAS OF GEOMETRICS

Site	Lane AADT	Avg. Friction Number
TBR 167	13.5K	43
TBR 168a	6.6K	43
TBR 171a	6.3K	45
TBR 171b	2.5K	48
Rt. 9 (S. of Poughkeepsie)	9.6K	33
IF-8 (Rt. 25A at Glen Cove)	4.3K	28
25A/0302/1061-1068	7.5K	28
110/0701/1005-1010	6.9K	23
110/0701/1077-1095	9.8K	25
347/0701/1121-1127	13.5K	29
454/0701/1031	9.3K	34
95I/X1M2/1000-1007	25.4K	31
95I/X1M2/1043-1045	25.0K	23
278I/X5M3/3028-3031	18.0K	32
907D/X5M2/3065-3067	13.8K	29

In each of the above pavement sections, friction measured within areas containing geometrics (intersections, curves, merges) were averaged.**This data shows that Wappinger Dolomite/ non-carbonate blends cannot be depended upon to provide the Programmatic Design Target Minimum friction (FN_{40} =32) on pavements having a Lane AADT of 4000 or greater.**

Figure A

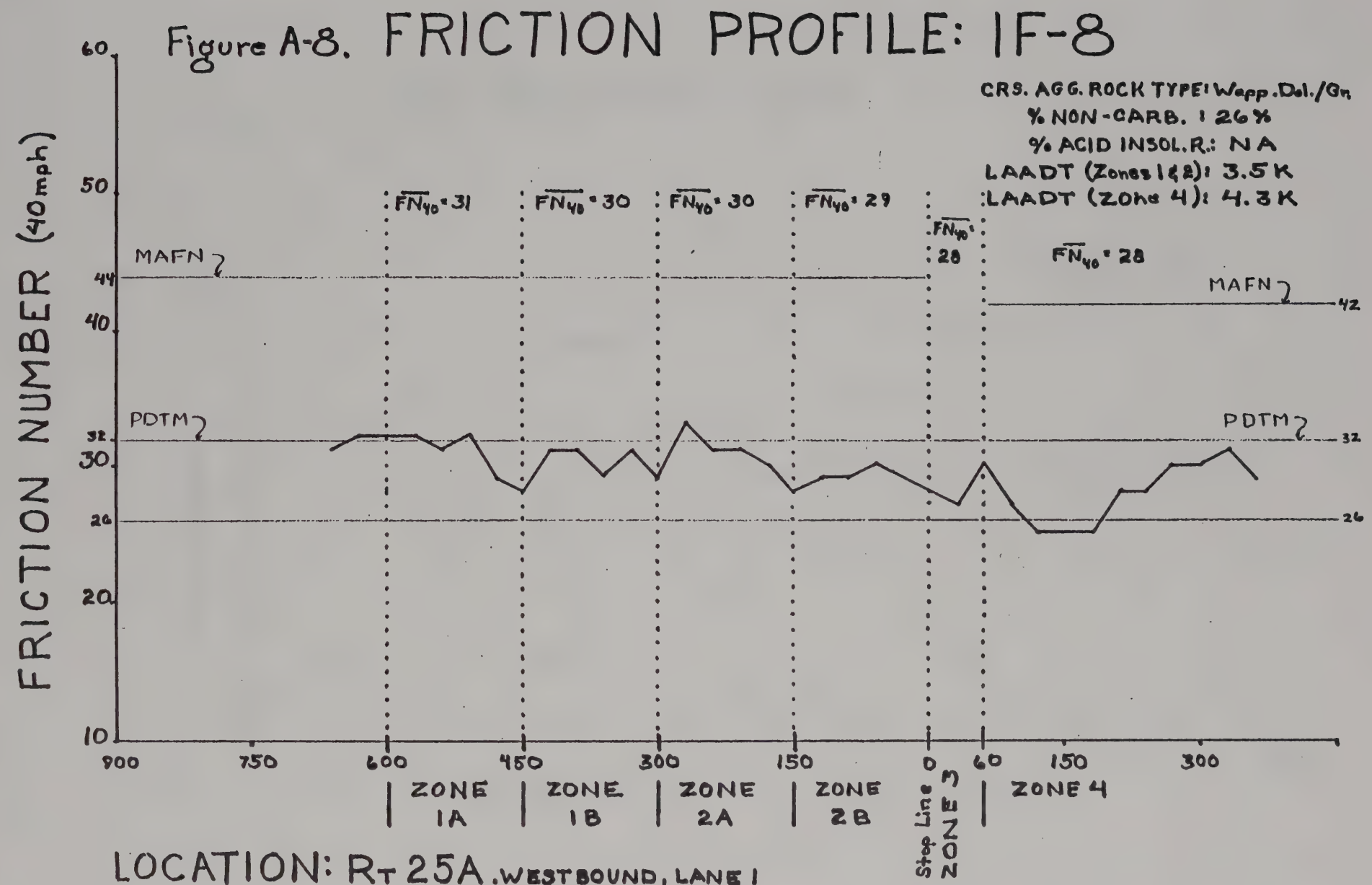


Figure A-8. FRICTION PROFILE: IF-8
CRS. AGG. ROCK TYPE: Wapp. Dol./Gn
% NON-CARB. : 26%
% ACID INSOL. R.: NA
LAADT (Zones 1 & 2): 3.5K
LAADT (Zone 4): 4.3K
FRICTION NUMBER (40 mph)
60
50
40
32
30
20
10
MAFN ?
PDTM ?
$\overline{FN_{40}}$ = 31
$\overline{FN_{40}}$ = 30
$\overline{FN_{40}}$ = 30
$\overline{FN_{40}}$ = 29
$\overline{FN_{40}}$ = 28
$\overline{FN_{40}}$ = 28
MAFN ?
PDTM ?
44
42
32
26
900
750
600
450
300
150
0
60
150
300
ZONE 1A
ZONE 1B
ZONE 2A
ZONE 2B
Step Line
ZONE 3
ZONE 4
LOCATION: RT 25A. WESTBOUND, LANE 1

Figure B

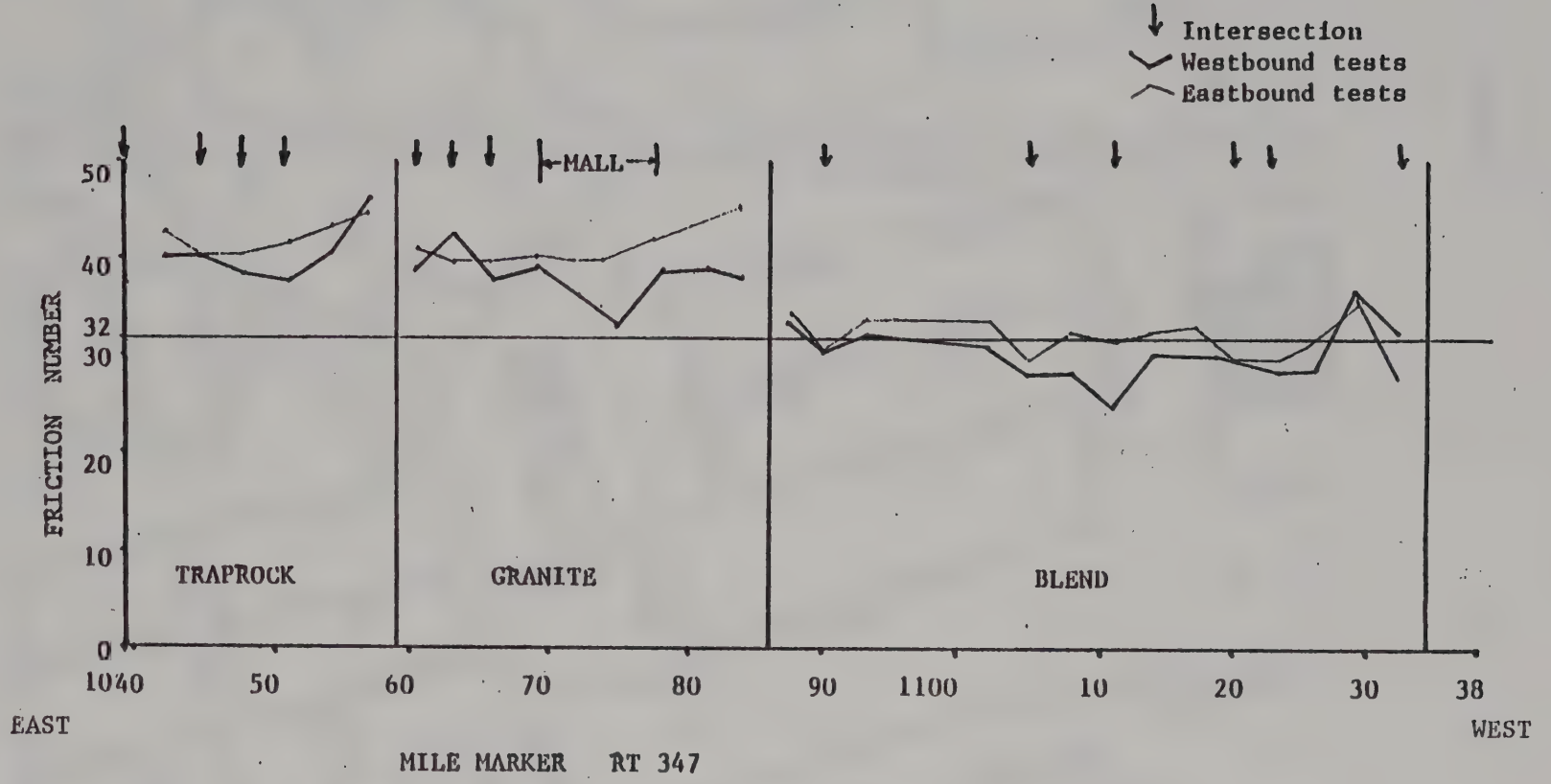
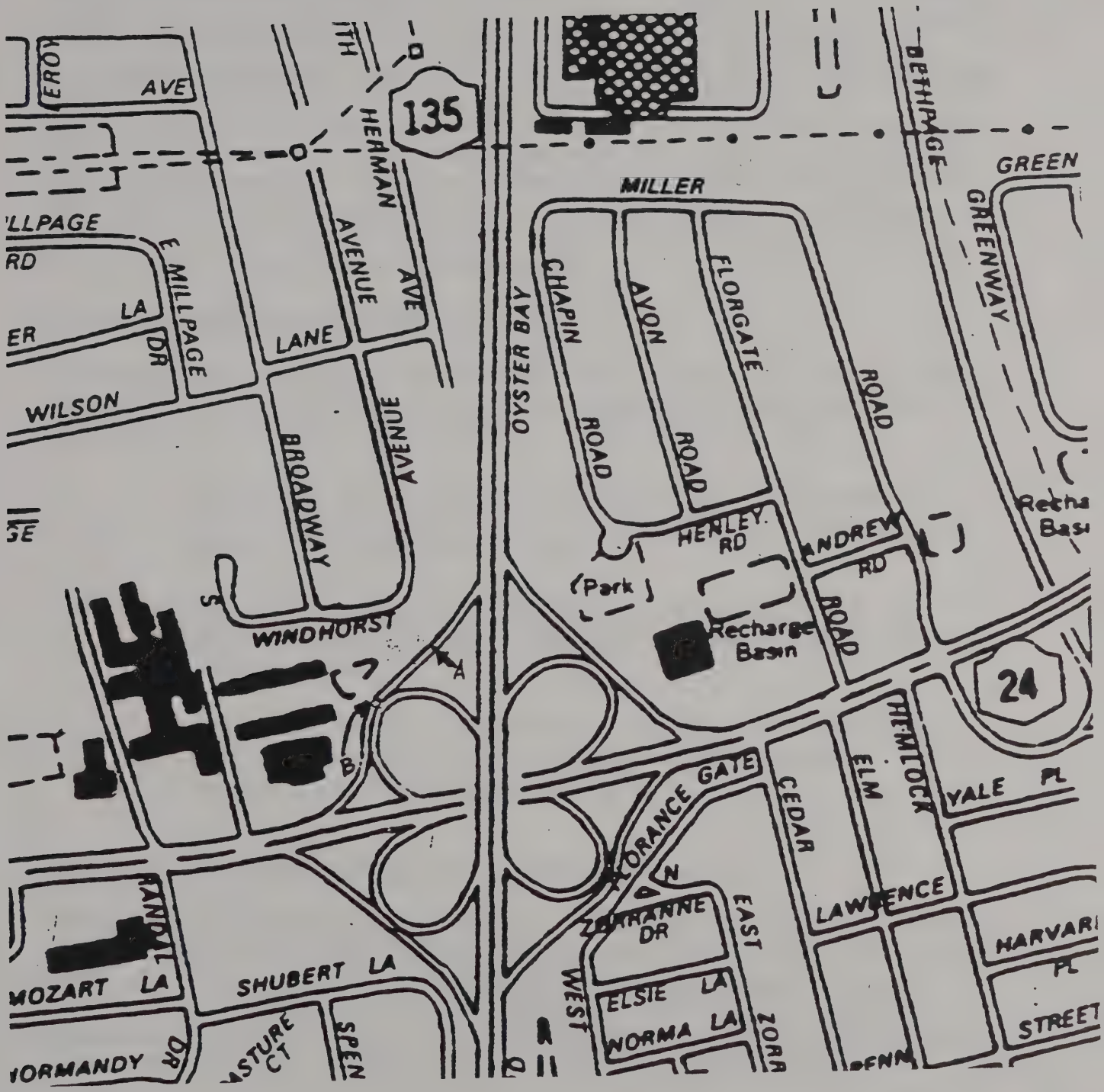

NY 347 FRICTION
Intersection
Westbound tests
Eastbound tests
MALL
FRICTION NUMBER
50
40
32
30
20
10
0
TRAPROCK
GRANITE
BLEND
1040
50
60
70
80
90
1100
10
20
30
38
EAST
WEST
MILE MARKER RT 347

Figure C



135
HERMAN
AVENUE
AVE
E MILLPAGE
LANE
WILSON
BROADWAY
AVENUE
WINDHORST
OYSTER BAY
MILLER
CHAPIN
ROAD
AVON
ROAD
FLORGATE
ROAD
BETHPAGE
GREEN
GREENWAY
HENLEY RD
ANDREW RD
ROAD
Park
Recharge Basin
24
HEMLOCK
ELM
CEDAR
YALE PL
LAWRENCE
HARVARD PL
STREET
FLORANCE GATE
ZORRANNE DR
EAST
WEST
ELSIE LA
NORMA LA
SHUBERT LA
MOZART LA
NORMANDY DR
A
B

Priority Investigation Location (PIL) List Summary

The Department's Traffic Engineering & Safety Division generates annual lists of Wet PILs based on the Department's Statewide Accident Surveillance System (SASS). Wet PILs are sites where the proportion of wet weather accidents significantly exceeds the statewide average.These Wet PILs are friction tested so that wet pavement conditions may be addressed as part of an overall remediation program. Regions 8, 10, and 11 contributed 81% (89 of 110) of the total sites to the 1997 PIL list, and 83% (109 of 132) of the total sites to the 1998 PIL list. The preponderance of PILs Downstate is due, in part, to its endemic very high traffic volumes which reduces friction, overall. Geometric and congestion factors, discussed above, exacerbate overall friction reduction, particularly in pavements containing Wappinger Dolomite. Roughly half the Downstate PILs have friction numbers (FN_{40}) below the Programmatic Design Target Minimum (PDTM) of 32, and, of those that have been examined, all contain Wappinger Dolomite, either 100% or as part of a blend with non-carbonate aggregate.

Department Guidance on Wet Road PILs

In 1996, the Department began to measure pavement friction routinely at all wet PILs identified annually by the Traffic/Planning Division. A joint memorandum by T. Werner and P. Mack, dated January 9, 1997 (reissued March 26, 1998), recommended actions as follows:

* When 33% or more of the FN_{40} friction test results on a Wet PIL segment are below 26, remedial action should be scheduled as soon as possible to improve the frictional quality of the pavement segment,

* In all other instances where FN_{40} friction results are below 32, the Wet PIL should be evaluated as soon as possible to determine if friction is contributing to skidding accidents.

* When all FN_{40} friction test results within the Wet PIL are 32 or higher, friction is not the likely cause of the wet road accident problem. Other factors contributing to accidents should be investigated.

Wappinger Dolomite Blends, High Traffic Volumes, and Geometrics

Table 3 lists pavement sites, of various traffic volumes, that contain Wappinger Dolomite / non-carbonate blends in areas of roadway geometrics (intersections, curves, lane merges), many sites are PILs and others are TBRs selected to test pavements containing the aggregate blend. The extremely diverse geometric conditions represented by these sites introduce variables that produce significant data scatter. However, all locations having friction numbers (FN_{40}) below the programmatic design target minimum of 32, have Lane AADTs of 4000 or greater.

Findings

Department studies on the performance of Wappinger Dolomite as a friction aggregate in asphalt pavement surface courses yield findings as follows:

1. Technical Report 92-1 and TRR 1418* reported that traffic intensity (lane AADT) is a controlling factor in the frictional performance of a given aggregate or aggregate blend.

2. Technical Report 92-1 reported, using data gathered where traffic is free flowing, Wappinger Dolomite can only be depended upon to provide programmiatic design target minimum friction ($FN_{40} = 32$) up to a traffic intensity of no greater than 4000 Lane AADT.

3. TRR 1418* reported satisfactory friction performance had been achieved using blends of carbonate and non-carbonate aggregates. These blends contained a minimum of 20% non-carbonate material in the coarse aggregate.

4. The Department's intersection scanning study, conducted in 1997 and 1998, found that pavement friction is diminished at high traffic volume intersecting roadways.

5. This report finds that pavement friction on surfaces containing blends of Wappinger Dolomite and non-carbonate materials, which exceed the minimum reqirement of 20% non-carbonate, but which are less than 40% non-carbonate, in the coarse aggregate, diminishes as lane AADT increases. This same relationship between pavement friction and lane AADT was reported with other aggregates in Technical Report 92-1 and TRR 1418*.This report also finds that geometric conditions, intersections,ramps, curves, and merging lanes, diminish pavement friction.

   Friction data from pavement inventory and "test-by-request" sites, representing Wappinger Dolomite / non-carbonate blends, show that congested roadways (greater than 15,000 lane AADT) generally have friction below the desired minimum. Moreover, curves, lane merges, and intersections have consistently lower friction than their "open road" counterparts. In the vicinity of these "geometrics", on roadways having lane AADTs of 4000 or greater, Wappinger Dolomite/non-carbonate blends cannot be depended upon to maintain friction above the minimum desired.

*TRR 1418: Skerritt, W.H., ***Aggregate Type and Traffic Volume as Controlling Factors in Bituminous Pavement Friction***, Transportation Research Record No. 1418, 1993

6. The Department's Statewide Accident Surveillance System 1997 and 1998 Wet PIL lists reported a significantly higher rate than the statewide average for wet weather accidents to Regions 8, 10 and 11. This area contributed 81% of the 1997 Wet PILs and 83% of the 1998 Wet PILs. Roughly half the Wet PILs tested in Regions 8, 10 and 11 were found to have friction numbers below the minimum desired (FN_{40}=32) and, of those that have been examined petrographically, all were found to contain Wappinger Dolomite, either 100% or blended with non-carbonate aggregate.

Recommendations

1. Extend the current restriction on the use of Wappinger Dolomite, as 100% of the coarse aggregate, to include its use as a blend with 20% to 40% non-carbonate coarse aggregate, in asphalt top course mixes used in areas containing geometrics (intersections, curves, entrance and exit ramps, and lane merges) where traffic volumes will equal or exceed 4000 Lane AADT during the design life of the pavement.

2. Extend the current restriction on the use of Wappinger Dolomite, as 100% of the coarse aggregate, to include its use as a blend with 20% to 40% non-carbonate coarse aggregate, in asphalt top course mixes used in areas where traffic volumes will equal or exceed 15,000 Lane AADT during the design life of the pavement.

3. Action should be taken by the Department to evaluate alternatives and implement changes in the friction aggregate specifications to achieve the programmatic design target minimum friction in the areas found in this report to be below target.

4. Friction on pavements made with various carbonate aggregates, and blends of carbonate and non-carbonate aggregates, in areas containing geometrics should be monitored through the Pavement Friction Inventory Program.

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